Scientific Visualization for Interpretation and Assessment of Damage in Structures Subject to Blast Loads

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Abstract

There has been significant activity in the computational structural mechanics community, in developing methods to identify, assess and predict the effects of explosive blast loading on structures. The use of high performance computing tools in analysis and prediction of blast loading has provided unprecedented insight and understanding on the mechanisms of failure, as well as methods to assess this damage in these cases. However, these analyses produce vast amounts of data, which are difficult to visualize. Researchers at Clark Atlanta University in collaboration with CEWES MSRC have developed a basic testbed to validate different visualization paradigms associated with different damage rules specifically for the visualization of blast analysis data. This paper outlines this framework and describes the approach adopted.

1.0 Background

In recent years, there has been significant activity in the computational structural mechanics community, in developing methods to identify, assess and predict the effects of explosive blast loading on structures. While this is not a new area, much of the work carried out earlier was restricted and not openly available. The use of high performance computing tools for the analysis and prediction of blast loading has provided an unprecedented insight and understanding on the mechanisms of failure, as well as methods to assess damage in these cases. The enormous quantity of data generated by these detailed analyses, itself poses a new kind of challenge: how does one make sense of this information, without drowning in its overwhelming volume? This paper outlines some of the innovative techniques being developed to overcome this bottleneck. Researchers at Clark Atlanta University in collaboration with CEWES researchers are investigating the use of immersive environments coupled with a consistent set of damage rules and associated visual paradigms, as tools for an easy-to-use and effective visualization environment. The authors have developed a basic testbed to validate different visualization paradigms associated with different damage rules specifically for the visualization of blast analysis data. This paper outlines this framework and describes the approach adopted. Some of the preliminary work in this effort will be presented and results from a sample case will be shown.

2.0 Approach

The use of high performance computing methods for developing detailed representations of physical phenomena leads to the generation of massive amounts of data as output. This data is well above the ability of any human to comprehend easily using traditional methods of post-processing. This implies that new methods are needed to effectively visualize this data. This is the focus of this effort. The results from ParaDyn analysis are used to assess damage suffered by the structure, and estimate residual capacity. This is a vital link in the decision making process and requires unequivocal indications to base decisions on. The approach in developing useful visualization techniques is predicated on the paradigm that for the purposes of damage assessment, a small subset of the output data is critical in providing the basis for decision making. In addition, using suitable damage criteria, the data associated with the field variation (vector or scalar) of the damage parameter can be notationally represented by some type of visual marker. These two combine to substantially reduce the computational burden on the visualization environment. Complementing this strategy, the use of well-structured graphical user interface (GUI) to permit higher levels of direct user interaction with the data model, reduces further the computational burden. The latter is achieved by providing the user with: (i)data filtering functions, (ii)scaleable fidelity/resolution, and (iii)self-navigational metaphors. In order to systematically diagnose the residual capacity of a given damaged structure, a methodology that utilizes an integrated modeling, analysis and visualization environment is essential. We have addressed this problem using a multi-pronged approach involving the development of a suitable visualization

platform, together with identifying appropriate damage criteria/rules, coupled with advanced visual paradigms to facilitate the user in making intelligent decisions based on the visualization of the available analysis data (Olatidoye, O., Sarathy, S., Jones, G., McIntyre, C., Milligan, L. [2]). Figure 1 illustrates the conceptual framework of this research effort.
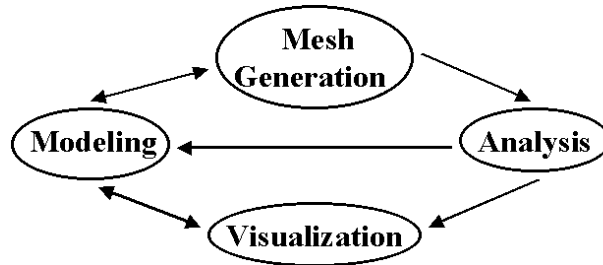

Figure 1: Overall Framework of the Integrated Simulation Environment

The framework shown above is currently being implemented by coupling a 3-D CAD tool with mesh generation software (INGRID) along with an analysis package (ParaDyn), such that a 3-D representation can be developed within the CAD modeling environment. The environment can then be used to generate the mesh based on the modeler's expertise. At the same time the boundary conditions, contact/interface specifications, loading conditions as well as material properties can be specified here in a straightforward manner. Thus, the analyst deals directly with the physical model and not with the discretized model. However, it is important from the standpoint of analysis tuning to be able to see the mesh generated, and this can be overlaid on top of the CAD representation.

3.0 Modeling and Analysis

The results shown in this paper highlight one case study of a sample building that was subjected to blast loads. The model of the building was generated in AutoCAD using polylines and 3D surfaces (Figure 2). From there, a corresponding INGRID finite element mesh was generated (by hand) based on the geometry of the AutoCAD model (Figure 3). This mesh served as the corresponding DYNA-3D input deck. To test the accuracy of the INGRID inputs and the grid generation, the mesh prescribed in the DYNA-3D input was converted back into the 3-D modeling environment. A DYNA-3D to AutoCAD (DXF) translator module was developed for this purpose. The comparison of the initial 3-D model and the mesh showed some discrepancies which are a result of flaws in the conversion code.
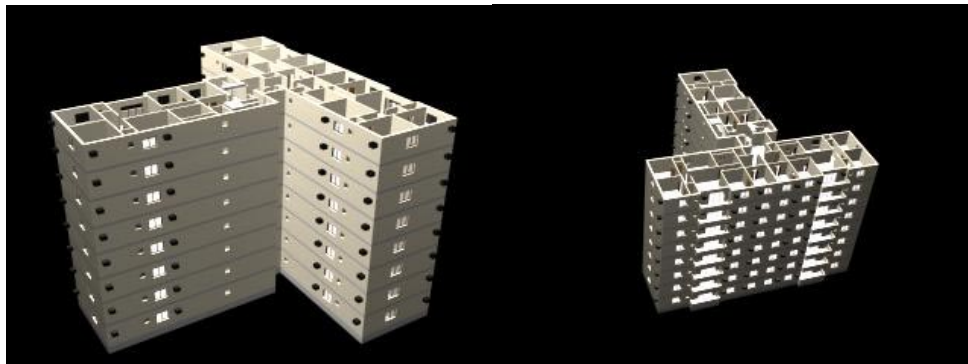

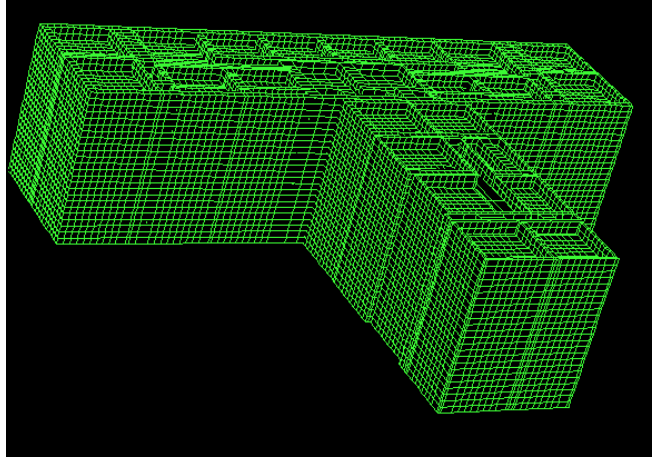**Figure 2: CAD Model Rendered View of Sample Building**

Figure 3: INGRID Mesh Generated For Sample Building

The dynamic analysis was performed by DYNA-3D, which considers the nonlinear, time-dependent effects of a blast wave acting on a structural model. Both load curves and material properties were specified in the input file. The results were saved in several output files. These files include an ASCII output file, a graphical output file, a time-history data file, a force data file, and a relaxed stress file.

3.1 Damage Assessment

We have conceptually developed a simple framework for visualization of structural analysis applications in general, and are applying this method to the damage assessment problems. At the heart of the visualization approach is the need to determine what damage criteria makes sense for damage assessment of structures subject to blast loads. We have conducted a literature survey of available methods used to determine, characterize and assess various type of damage inherent in structures subject to impact and blast loading. We have identified some preliminary approaches, which could potentially aid in the visualization of the large data sets from the ParaDyn analyses. Our basic approach in treating the structural analysis output is to differentiate it into three levels; (i)regions with material failure, using stress, strain or energy density descriptors, (ii)regions with damage based on a combination of material and structural failure, and (iii) reduced structural performance or capacity. The first type of failure is evident on an elemental level, and can be easily identified by comparing the individual elemental levels with those of a threshold. This is the primary method currently used to determine damage. The second type of region may have localized zones or patches of failure leading to less than total damage to the structure. This would manifest itself in clusters of elements close to or beyond failure thresholds. Finally, the third level of damage deals with the structural functioning of *members* and not elements. Here, a grouping of elements by design function is viewed with respect to the threshold load capacity. This capacity or function may be impaired due to either regions of type (i) or (ii) damage but not sufficient to render the member inoperative. These three levels represent a hierarchy of damage descriptors, which will provide more pertinent information to the decision-maker than just the filed variations of the stress or strains over the entire structure. Using this approach we have developed a sample case where a building is subject to empirically computed blast loads. This problem has been analyzed in DYNA-3D/ ParaDyn using existing damage criteria. The stress data is converted and viewed within the visualization environment. Currently, only type (i) regions are displayed.

3.2 Damage Assessment Methods

The survey of available literature on relevant damage assessment methods as applied to structures subjected to blast loading is somewhat limited. We will briefly outline our findings in this section. A more comprehensive report can be found in "A Representative Survey of Blast Loading Models and Damage Assessment Methods for Buildings Subject To Explosive Blasts" (Olatidoye, O., Sarathy, S., Jones, G., McIntyre, C., Milligan, L. [3]). Most of the articles focus on either the potential and observed failure mechanisms or on the use of various constitutive models to characterize the inelastic material behavior. A substantial number of articles address the issue of how finite element analysis can be used to address the behavior of structures subject to blast loading through the use of refined elements, hybrid material models and special elements to allow changes in the integrity of the structural members. An attempt was made to review some of the related articles in the arena of damage models in seismic

applications. Unlike the blast loading cases, there are multitudes of articles which address the damage assessment methods; some of these may be useful for the blast loading applications. The results of the literature review are categorized under three topics, (i)constitutive models, (ii)failure models and (iii)damage criteria. While several papers do address some or all three of these areas, the above taxonomy will be used to group based on the primary focus of the articles' content.

3.2.1 Constitutive Models: Material models for civil structures are broadly divided between those for steel and for concrete, include both continuum and layered approaches useful in the numerical computation of these models. The models for steel typically range from ideally elastic/plastic, strain hardening, shear stiffness degradation, as well as inelastic models with multiple linear regions (developed for aluminum members). Those for concrete include elasticity, classical plasticity, cap plasticity, bounding surface plasticity, endochronic theory, fracture mechanics, continuum damage mechanics, and viscoplasticity. Several hybrid models have been proposed in recent years, which have sought to combine two or more of these approaches, in order to predict the behavior in specific load and strain regimes

3.2.2 Failure Models: A majority of articles in this area focus on identifying potential failure mechanisms based on the nature of the loading and the expected structural response of the structure. Here, the failure modes for different structures are analyzed based on local material failure as well as fracture, buckling and yield line analyses. These range from failure mechanisms for specific structural configurations (sandwich plates) to general-purpose beam analysis. On the dynamic analysis side, the duration of loading combined with the expected natural frequency of the structure determine the validity of assuming the blast loading to be either impulsive or quasi-static. The former case is justifiable when the natural frequencies of the structure are such that the positive phase duration of the blast is much smaller that that of the structure, thus, ensuring very little response during the loading phase. The latter case corresponds to very long positive phase duration of the blast relative to the structural response times.

3.2.3 Damage Criteria: The articles ranged from the use of ductility factor for damage assessment, energy based damage models, as well as combinations of displacement and energy criteria for damage assessment. The energy based damage models include adaptations of classical low cycle models based on energy dissipation, stiffness degradation under reversed cyclic loading, vibrational characteristic based models, other hybrid models combining such structural parameters, and combinations of excessive deformation and cumulative plastic strain. Other numerically based methods are based on neural networks, which use patterns in response data to provide regression analysis and damage indices useful for damage assessment.

In summary, while there are many material and constitutive models available, however, a much smaller subset of articles address the methods that can be used for damage assessment. The two main approaches here seem to be (i)use of stochastic damage parameters and (ii)use of simplified failure mechanisms in conjunction with either displacement/strain based or energy based criteria. Nevertheless, none of the articles surveyed provides a consistent approach to damage assessment that can be applied using large computational methods based on high performance computing, and visualized in a manner that yields relevant information on the damage phenomena effectively. We believe that some work still remains in combining these different approaches, where appropriate, and applying them within the visualization framework.

4.0 Visualization of Damage in Blast Loaded Structures

Currently, we have conceptually developed a visualization strategy for structural analysis applications in general, and are now working to apply it to the damage assessment type problems. At the heart of the visualization approach is the need to determine what damage criteria makes sense for damage assessment of structures subject to blast loads. As a result, we have identified a potentially viable damage assessment scheme. In this method, the output of the structural analysis is broken into three levels; (i) regions with material failure, using stress, strain or energy density descriptors, (ii) regions with damage based on a combination of material and structural failure, and (iii) reduced structural performance or capacity. The first type of failure is evident on an elemental level, and can be easily identified by comparing the individual elemental levels with those of a threshold. This is the primary method currently used to determine damage. The second type of region may have localized zones or patches of failure leading to less than total damage to the structure. This would manifest itself in clusters of elements close to or beyond failure thresholds. Finally, the third level of damage deals with the structural functioning of *members* but

not elements. Here, a grouping of elements by design function is viewed with respect to the threshold load capacity. This capacity or function may be impaired due to either regions of type (i) or (ii) damage but not sufficient to render the member inoperative. These three levels represent a hierarchy of damage descriptors that will provide more pertinent information to the decision-maker than simply the field variations of the stress or strains over the entire structure.

The results of the DYNA-3D code are used by the in-house Design-Oriented Intelligent System Environment (DOISE) (which is under development at the ViSiDel) to provide an immersive representation of the stress and displacement response of the structure within a Virtual Reality (VR) environment. Currently, only the geometry from DYNA-3D has been completely translated into the DOISE VR environment (Figure 4). The translation of the structural response into DOISE is now being pursued. However, a similar effort in the past successfully calculated the structural response of a high-rise building subjected to wind loads and imported the data into a virtual environment (Olatidoye, Sarathy, Jones [1]). Figure 5 provides an illustration of these visualization capabilities.
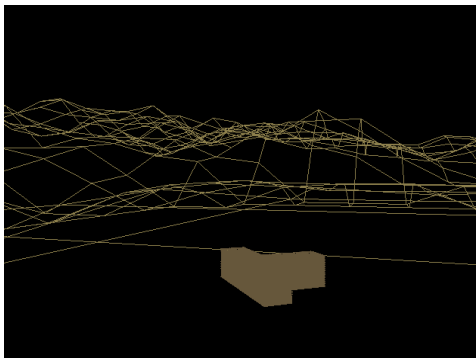
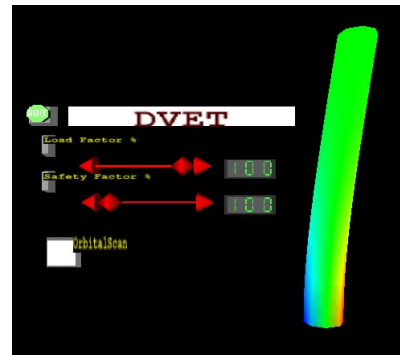

Figure 4: Sample Building Rendered in DOISE

Figure 5: Visualization of Stresses and Displacements in Virtual Environment

Summary

A basic approach to visualizing damage within the context of buildings subject to blast loading has been developed. The effort included devising a consistent damage assessment strategy for use in the visualization of damage. This approach has been implemented in part on a sample building using blast loads. A CAD model was generated, and from this model a finite element mesh was developed. INGRID was used to generate the mesh, while DYNA-3D was used to analyze the model. Some of the modules to convert data between AutoCAD, INGRID, DYNA-3D and DOISE visualization environment have been developed.

Acknowledgement

References

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3. Olatidoye, O., Sarathy, S., Jones, G., McIntyre, C., Milligan, L., "A Representative Survey of Blast Loading Models and Damage Assessment Methods for Buildings Subject To Explosive Blasts", CEWES MSRC PET Technical Report No. 98-36, Vicksburg, MS, 1998.

Keywords: damage assessment, residual capacity, structures, high performance computing, scientific visualization, blast loading